Chapter 4.1

Clinical EMG and glossary of terms most commonly used by clinical electromyographers

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Introduction

Electromyography is best regarded as an extension of the clinical neurological examination and taken outside this context results are often meaningless and difficult to interpret. Test design must be based upon the clinical problem if the most comprehensive and valid information with a minimum number of procedures is to be achieved, and predeterminded stereotyped protocols should be discouraged. However, the standards within a particular technique used (needle EMG, nerve conduction) should be rigidly adhered to if results are to be reproducible.

Clinical application of electromyography dates back to the 1930s. Lindsley (1935) described variations of motor unit potential amplitude during voluntary muscle activity in a patient with myasthenia gravis, and in 1938 Denny-Brown and Pennybacker (1938) described fibrillation and fasciculation spontaneous potentials in denervated muscles. Over subsequent years technology improved allowing more confident differentiation between myopathic and neurogenic disorders, the ability to detect subclinical disorders, assessment of the extent and the severity of a lesion, accurate localization of the site of the lesion and in many cases offering a reasonable differential diagnosis.

Major contributors to electromyography during its developmental years were Kugelberg (1947, 1949) in Stockholm, who described the motor unit changes in neuromuscular disorders, and Buchthal and his co-workers in Copenhagen (Buchthal and Clemmesen 1941; Buchthal et al. 1957) who quantitatively measured the motor unit. Later, Ekstedt, Stålberg and their associates (Ekstedt 1964; Ekstedt and Stålberg 1973; Stålberg et al. 1974) devised single fibre electromyography (SFEMG), which proved to be very useful in ‘‘morphological’’ characterization of the motor unit. Subsequently macro- and scanning-electromyography enabled measurement of the entire motor unit in a three-dimensional plane (Stålberg 1980). Other important steps

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included turns analysis (Willison 1964), results of which depend on the degree of muscle contraction, and decomposition methods (LeFever and DeLuca 1982) that serve to semi-automatically recognize different characteristics of the motor unit action potential.

**Methodologies**

Most of these are detailed further in subsequent chapters and here only brief commentary will be made on some of them.

*Conventional needle electromyography*

Either a concentric needle electrode or monopolar electrode are commonly used. Both have their place. Monopolar electrodes are cheaper, less painful and therefore excellent for examination of the paraspinal muscles and have a larger pick-up area so that spontaneous activity (fibrillation, positive sharp waves, etc.) are more readily recorded. Concentric electrodes, because of their more restricted pick-up, allow for better “morphological” view of the motor unit so that it is possible to qualitatively analyze the motor unit in terms of its complexity (fibre density) and stability (jiggle, jitter). A trigger-delay line, available now on all commercial equipment makes qualitative assessment of the motor unit easy and is essential for quantitative measurements. Most modern EMG equipment has automatic motor unit potential analysis built in. The differential amplifiers that have been in use for some time are of considerable help in removing the background noise. A band pass of 20 Hz to 10 kHz is frequently used but background noise can be further improved by narrowing the recording band pass to 500 or 1000 Hz and 10 kHz as is done routinely in single fibre EMG.

*Single fibre electromyography (SFEMG)*

SFEMG records the electrical activity generated by a single muscular fibre, so that the interactions among muscle fibres of the same motor unit can be studied. SFEMG may be done in voluntary activated muscles and with axonal micro-stimulation (Stålberg and Trontelj 1979; Trontelj and Stålberg 1992). In the first case, a needle electrode with a small recording surface (usually 25 μm in diameter) is inserted into a weakly contracted muscle. Single fibre potentials have a constant shape, generally biphasic, with an amplitude of 0.5–10 mV, a total duration of less than 2 ms, and a rise time of the positive–negative deflection less than 200 μs. A single potential is usually recorded; however, with small electrode movements it is possible to record additional action potentials from two or more single muscle fibres of the same motor unit. Therefore, it is possible to measure the time-discharge interval among action potentials generated by the same motor unit. The interpotential discharge interval varies with conduction time through the terminal nerve branches, the muscle fibres and the integrity of motor end-plates.

*Macroelectromyography*

Conventional needle electromyography and SFEMG yield information limited to the electrical activity of only part of the motor unit. Macroelectromyography was developed to study the activity of the entire motor unit (Stålberg 1980). To this aim, a special recording electrode, which is a modified SFEMG electrode, is used. This electrode has a 25-μm diameter platinum wire exposed in a side-port 7.5 mm proximal to the tip. The electrode cannula is made of steel and has a diameter of 0.55 mm; it is insulated to within 15 mm of the tip. With this electrode inserted into the muscle it is possible to obtain a non-selective recording from the cannula during a weak contraction. The macropotential amplitude is the most valuable characteristic to measure and is positively correlated with the size and number of muscle fibres in the motor unit. The amplitude is typically increased in neurogenic disorders, when reinnervation has occurred, and may be reduced in myopathic diseases. Scanning EMG is an extension of macro-EMG and allows the potential to be recorded as the needle tip is advanced through the motor unit. This then gives a three-dimensional view of the motor unit. Macro-EMG reveals that in a disease the motor unit is not uniformly involved: some parts may be normal and others very abnormal.
**Precision decomposition of EMG signals**

The decomposition technique was designed to identify the waveform of individual motor unit action potentials from the electromyographic recording during isometric contraction. It was mainly aimed at the detailed study of firing pattern. The method is based on a special electrode and on computer analysis (Basmajian and DeLuca 1985). The percentage of correct motor unit action potential that is identified depends on the quality of the signal ranging from 75 to 90% in the automatic mode.

The precise decomposition EMG requires a special quadrilinar electrode, whose salient feature is its 4 detection surfaces situated in a side-port of the needle cannula. These detection surfaces are connected in a bipolar configuration to provide 3 differential outputs, each of which conducts an EMG signal. Multiple channel recording mode permits the recording of the electrical activity from 4 to 5 motor units and gives 3 different representations of the same motor unit. With this technique one may select and precisely represent a motor unit during moderate to strong muscular effort.

**Quantitative electromyography during strong contraction**

Quantitative EMG analysis automatically estimates electromyographic activity during contraction exerted against a definite load. Turns analysis was developed by Willison in 1964 to provide information on the number of times the signal reverses its polarity in 1 s and on the averaged amplitude of all electromyographic components. Therefore, results depend on the contraction strength. The muscular electrical activity is recorded by means of needle electrodes at an isometric load (Willison used loads of 2–5 kg depending on the muscle being examined). Various methods have been developed for turns analysis with the aim of making it independent of the contraction force (Fuglsang-Frederiksen et al. 1976; Stålberg et al. 1983). In myopathic disorders the mean turns count is increased, while in chronic partial denervation there is an increase in the inter-turn mean amplitude.

**Nerve conduction studies**

**Motor conduction velocity**

Normal values for ulnar, median, radial and peroneal nerve motor conduction velocities were established over 50 years ago (Hodes et al. 1948), and this was the first time that an objective method for evaluating patients with suspected peripheral nerve disorders was applied.

**Stimulation**

The principle of the method is very simple: bipolar, percutaneous, supramaximal, electrical stimulation of peripheral nerve motor fibres evokes time-related responses in the muscles that they innervate. The cathodal stimulating electrode is positioned distally. A supramaximal stimulus (20–30% above maximum) ensures that all the fastest conducting fibres are activated. On the other hand if the stimulus is too strong it may cause cathodal blocking and/or cause stimulus spread to a nearby nerve which will result in a falsely large response. This situation is not uncommon when stimulating the median or ulnar nerves in the region of the elbow. A lower stimulus intensity can be used with stimulating needle electrodes, thus avoiding the spread of current. In some situations the use of needle stimulating electrodes is advantageous. These situations include a high threshold as occurs in disease and a deeply situated nerve as when attempting to stimulate the spinal roots and the sciatic nerve.

The evoked compound motor action potential (CMAP) also called a direct or M wave and the time interval between its onset and the stimulus artifact is referred to as the latency measured in milliseconds (ms). Most modern EMG equipment has the capability to determine the onset of the response automatically with considerable accuracy. Distal stimulation incorporates not only the time taken to travel along the nerve trunk, but also the nerve terminals, neuromuscular junction and muscles fibres. In order to determine conduction velocity along the fastest motor fibres it is necessary to stimulate the nerve at two or more additional proximal sites. Conduction time between the segments, measured in ms, is determined by the
latency difference between the sites of stimulation. Conduction time is converted into velocity (measured in m/s) by distance/time. Inherent in the conversion is additional inaccuracy which is minimized by using a conduction distance (distance between two stimulating sites) of >10 cm.

Velocity along slower conducting motor fibres can be obtained by exploiting the collision principle. With this technique, either two submaximal and supramaximal stimuli are simultaneously applied in the proximal and distal points of a nerve (Thomas et al. 1959), or the time interval between two paired supramaximal electrical shocks that stimulate a proximal and a distal point of a nerve is progressively modified (Hopf 1962).

**Recording**

As the size (amplitude or area) of the CMAP depends on the number of the nerve fibres that are stimulated and the number of muscle fibres under the recording electrode, needle electrodes are not suitable for recording. The active surface recording electrode should be positioned over the muscle endplate and the reference electrode over a distal relatively inactive structure such as a distal phalanx when recording from thenar or hypothenar muscle complexes.

**Sensory conduction velocity**

Dawson (1956) made it possible to record sensory nerve action potentials (SNAPs), which are in the order of 5–50 μV in amplitude, by developing the first averager. Two years later, Gilliatt and Sears (1958) recorded SNAPs in a clinical setting stimulating digital sensory nerve fibres of the fingers and recording the evoked response proximally from the nerve trunk in the arm. Since that time, the recording of sensory action potential (SAP) from peripheral nerves has become routine.

**Stimulation**

The sensory potentials can be evoked by orthodromic or antidromic stimulation. In some laboratories the digital nerves are stimulated with ring electrodes placed around one or more fingers and evoked responses are recorded proximally along the nerve course (orthodromic method). Sensory conduction can be also measured with the antidromic method. With this technique the placement of the stimulating and recording electrodes is reversed, so that the stimulating electrode is proximal and the recording electrode distal. Both latencies and conduction velocities measured with the antidromic method are identical as with orthodromic measurements. However, little information is obtainable from the SNAP amplitude if a mixed nerve is explored, since in this case the stimulating current must be kept below the threshold for motor fibres. If motor fibre stimulation cannot be avoided, care must be taken to differentiate a SNAP from a volume-conducted muscle action potential. The antidromic method is preferable in purely sensory nerves, such as the sural nerve and the distal superficial segment of the radial nerve but is also often used for digital nerves.

**Recording**

Bipolar surface recording electrodes are commonly used. They are comfortable for the patient and are generally satisfactory. However, surface electrodes do not always pick-up small potentials from proximal nerve segments. The electrodes are placed longitudinally along the nerve with an inter-electrode distance of 2–3 cm.

Near-nerve needle recording is infrequently used, although this method gives added information regarding the dispersion of the SNAP and allows one to calculate conduction through slower conducting sensory fibres. However, it is time-consuming, requires extensive averaging and gives inconsistent amplitudes in repeated studies from the same nerve in the same subject (Gassel and Trojaborg 1964). This is because it is impossible to place the needle at a constant distance from the nerve.

The latency of SNAPs can be measured to its onset, designated as the first positive peak of the potential. This reflects the impulse propagation along 80% of the fastest fibres (Buchthal and Rosenfalck 1966) and amplitude is measured peak-to-peak (first positivity to the largest, usually the first, negativity). Latency can also be measured to the main negative peak, which is usually much larger than the initial positivity. The amplitude is then measured from baseline to peak. Peak-to-peak
amplitude of SNAPs is related to the number of excited fibres, to their temporal dispersion and to the distance of the nerve from the recording electrode.

The calculation of peripheral nerve conduction velocity is prone to errors. Caution should be exerted to take account of the numerous anatomical innervation abnormalities (Mannerfelt 1966; Wilbourn and Lambert 1976). Also technical errors can be a problem; for instance, the use of inappropriate stimulus intensity or an incorrect measurement of distances between stimulating and recording sites. Submaximal stimulation could fail to excite some of the fastest fibres, giving an apparent reduced conduction velocity; too strong stimuli could cause the current to spread to adjacent nerves or along the same nerve. Age affects conduction velocities: adult values are reached between the age of 2 and 5 years, while conduction velocity declines with advancing age (Rosenfalck and Rosenfalck 1975; Ludin 1980). Conduction velocity of peripheral nerves is temperature dependent (Ludin and Beyeler 1977). Lowering the temperature will slow velocity but increase the SNAP amplitude.

Conduction abnormalities in disease

Conduction slowing of more than 40% is characteristic of demyelinating neuropathies. Both motor and sensory fibres may be affected, but not necessarily to the same extent. The terminal motor latency may also be prolonged (Gilliatt 1966). Muscle (CMAP) or nerve action (SNAP) potentials are typically dispersed and decreased in amplitude with increasing conduction distances. This is more typical of acquired demyelinating neuropathies in which the degree of conduction slowing also varies amongst different nerves and often also along the same nerve. Focal severe slowing or conduction blocks are not infrequent. In contrast, in hereditary neuropathies conduction velocity is uniformly slowed, often markedly slow. However, conduction block is not seen (Lewis and Sumner 1982). Conduction block is best defined in clinical-electrophysiological terms. It is paralysis or paresis with the ability to stimulate a nerve distal to the lesion and induce muscle movement as well as record a CMAP. Conduction block can only be determined in motor fibres. SNAPs have a rapid rise time compared to the CMAP and physiological ‘block’ occurs in sensory fibres because of phase cancellation when the conduction distance is more than a few centimeters.

In axonal neuropathies, as long as one or two fast conducting axons remain intact the conduction velocity is either normal, or only mildly reduced (Gilliatt 1966). CAMPs and SNAPs are typically small and the reduced amplitude is a measure of axonal loss. In these cases abnormalities are more likely to be found in the most distal segments of the nerves (Casey and Le Quesne 1972). Most axonopathies are acquired and are typically drug induced or due to deficiency of essential nutrients.

In focal nerve lesions conduction studies are helpful in localizing the lesion and give information as to whether there is axonal continuity, axon loss, demyelination or a combination of these. The conduction abnormalities vary according to the severity of the lesion: in mild compressive lesions focal conduciton slowing or localized conduction block may be the only abnormalities. There may also be dispersion of the CMAP. If axonal degeneration supervenes, reduction of the CMAP or SNAP can be marked. Inability to stimulate the nerve above or below the lesion may indicate that there is >90% axon loss or increase of excitability threshold.

Assessing proximal nerve lesions is not always easy. F-waves, H-reflexes, somatosensory evoked potentials and nerve root stimulation through a monopolar needle electrode or using magnetic stimulation (cave: submaximal stimulation) can all be helpful. These techniques are discussed in other chapters. Ganglionopathies which are diseases of the dorsal root ganglion per se are frequently associated with complete absence of the SNAP.

References


